Analysis of Students' Conceptual Difficulties in Learning Linear Aljabar in Higher Education

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Abstract.

This study aims to analyze students' conceptual difficulties in learning Linear Algebra at STAI Al Hikmah Tebing Tinggi. The research employed a descriptive qualitative approach, with data collected through diagnostic tests, in-depth interviews, and documentation. The results indicate that students experience significant conceptual difficulties in four main aspects: systems of linear equations, matrix operations and their properties, elementary row operations, and abstract concepts such as vector spaces and linear transformations. The factors contributing to these difficulties include weak prerequisite knowledge, ineffective teaching methods, a lack of meaningful practice problems, limited learning resources and instructional media, and low learning motivation. These conceptual difficulties hinder students' understanding of subsequent courses that require Linear Algebra as a prerequisite. Therefore, improvements in instructional strategies oriented toward conceptual understanding, the use of visualization technologies, the development of contextual learning materials, and the implementation of active and collaborative learning approaches are necessary to enhance the quality of Linear Algebra instruction.

Keywords*: Conceptual difficulties; learning and linear algebra.*

I. INTRODUCTION

Linear Algebra is a fundamental and compulsory course in many college programs, particularly in mathematics, statistics, and other applied sciences. The course covers vector spaces, linear transformations, systems of linear equations, determinants, eigenvalues, and eigenvectors, requiring a thorough understanding of concepts and the ability to think abstractly. Linear algebra is known for its high level of abstraction, which often presents difficulties not only in procedural aspects but especially in conceptual ones (Subedi, 2025). The issue of conceptual understanding in Linear Algebra has attracted the attention of many mathematics education researchers because it directly impacts students' ability to solve complex problems. Conceptual understanding refers to students' ability to not only follow algorithms or procedures but also understand the meaning and interrelationships between concepts. This includes the ability to represent concepts symbolically, link concepts, and apply theories to new situations. Previous research has shown that students often struggle to grasp abstract concepts such as vector spaces and subspaces, which form the basis for subsequent topics in Linear Algebra. These difficulties extend beyond calculation skills to higher cognitive abilities such as representing and connecting mathematical symbols meaningfully (Rumiati & Novitasari, 2025).This phenomenon of conceptual difficulty is also proven by a number of empirical studies in the context of higher education.

For example, a study on student errors in solving Linear Algebra and Matrix problems showed that the dominant type of error made by students was conceptual errors (38.46%), indicating that the greatest difficulty is not only in calculations, but also in understanding the underlying mathematical structure (Maimunah, Qadarsih & Nadeak, 2025). In addition, other studies report that many students still rely on lecturer instructions and are less able to interpret problems independently, especially when faced with questions that require conceptual analysis and critical reasoning (diagnostic test results Al-Khawarizmi Journal, 2025).Students' difficulties in learning Linear Algebra can be influenced by various factors, including the abstract nature of the material, the lack of strong prerequisites from previous materials, learning strategies that do not accommodate conceptual understanding, and students' low metacognitive

abilities in managing their own thinking processes (Subedi, 2025). This is in accordance with the findings of researchers at STAI AL Hikmah Tebing Tinggi who found that students often only focus on procedural or mechanical aspects without understanding the meaning behind the mathematical operations they perform, so that when faced with problems that require in-depth understanding, they experience major obstacles.

Thus, learning Linear Algebra needs to be designed in such a way that it is not only oriented towards the final result, but also able to build a strong conceptual understanding. Furthermore, technological developments and online learning present new challenges in learning Linear Algebra. Research on learning difficulties in Linear Algebra in the context of online learning reveals that limited direct interaction and lack of immediate feedback can exacerbate students' conceptual difficulties, especially when the learning process is not supported by appropriate strategies such as direct guidance or the use of visual aids to clarify abstract concepts (Farida & Puspita, 2025).Based on these phenomena, it is important to conduct research that specifically analyzes students' conceptual difficulties in learning Linear Algebra in higher education. This research aims to systematically describe the types of difficulties experienced by students, the factors that cause them, and how these difficulties affect their learning process.

II. METHODS

This study employed a qualitative approach with a descriptive design. This approach was chosen because the study aimed to deeply understand the forms of conceptual difficulties experienced by students in learning Linear Algebra, as well as the factors that influence them. This approach allowed researchers to holistically explore students' experiences, understanding, and thought processes within a natural learning context.The research subjects were students of the Mathematics Education study program at STAI Al Hikmah Tebing Tinggi who had taken the Linear Algebra course. Subjects were selected using a purposive sampling technique, selecting students deemed capable of providing relevant information related to conceptual difficulties based on their academic performance and engagement in lectures. The number of subjects was adjusted to meet the required data depth until information saturation was achieved.Data collection techniques included diagnostic tests, in-depth interviews, and documentation.

Diagnostic tests were used to identify students' conceptual difficulties in linear algebra, such as understanding vector spaces, systems of linear equations, and linear transformations. In-depth interviews were conducted to further explore students' reasons, learning experiences, and thought processes when confronted with these concepts. Documentation in the form of Semester Learning Plans (RPS), teaching materials, and student work results served as supporting data.Data analysis was conducted using an interactive analysis model that includes data reduction, data presentation, and conclusion drawing. Test and interview data were reduced to identify key themes related to students' conceptual difficulties. Furthermore, the data were presented in narrative descriptions and categorization tables for ease of understanding. Data validity was maintained through source and technique triangulation techniques, as well as member checking with the research subjects. Thus, the research results are expected to provide a comprehensive picture of students' conceptual difficulties in learning Linear Algebra in higher education.

III. RESULT AND DISCUSSION

A. Research result

1. Students' Conceptual Difficulty Level

Based on the results of the diagnostic test given to students after learning the material on systems of linear equations, matrices and their operations, and determinants, various levels of conceptual difficulty were found to be quite significant. This diagnostic test was designed to measure students' understanding of basic concepts and their ability to apply the concept of understanding linear algebra to problem solving. Analysis of the test results shows that the average score of students' conceptual understanding at STAI Al Hikmah Tebing Tinggi is still in the poor category, which indicates that some students have not mastered the concepts in depth. Many students are able to work on problems procedurally, but experience difficulties when faced with problems that require conceptual reasoning and understanding mathematical meaning. These findings confirm research by Hanifah and Nawafilah (2021), which found that students experience

learning difficulties in Linear Algebra. These difficulties are characterized by several indicators, including a lack of thoroughness in understanding problems, errors in number operations, an inability to apply elementary row operations, and weak logical abilities in systematically organizing problem-solving steps. Furthermore, students tend to memorize formulas without understanding the underlying concepts, making them prone to errors when the problem context is slightly modified.These conceptual difficulties not only impact students' low academic achievement in Linear Algebra but also have the potential to hinder students' understanding of advanced courses that require linear algebra as a prerequisite, such as numerical methods, vector analysis, and mathematical statistics. Therefore, efforts are needed to improve learning strategies that emphasize conceptual understanding, mathematical reasoning, and the interrelationships between topics to minimize students' conceptual difficulties.

2. Types of Conceptual Difficulties

An in-depth analysis of students' answers identified four main categories of conceptual difficulties in learning linear algebra at STAI Al Hikmah Tebing Tinggi.

a. Difficulty Understanding the Concept of Linear Equation Systems (SPL)

Students have difficulty identifying the consistency of a system of linear equations and determining the type of solution (single solution, infinite solution, or no solution). Students tend to focus on the mechanical procedures of elimination and substitution without understanding the geometric meaning of the system of equations. The results of the study indicate that not all students are able to explain the relationship between the rank of the coefficient matrix and the rank of the augmented matrix with the consistency of the SPL. They simply memorize the rule that "if the rank is the same then it is consistent" without understanding the reasoning behind it.This difficulty is reinforced by findings from in-depth interviews with 12 purposively selected students. Student M01 stated: "I can solve SPL using Gaussian elimination, but if asked whether this system has a solution or not before calculating it, I don't know how." A similar statement was made by student M07: "The concept of rank is abstract, ma'am, I don't understand how it relates to solving equations." This finding is consistent with research by Farida et al. (2021), which found that students experience difficulties in learning linear algebra due to a lack of understanding of basic concepts, particularly in identifying and interpreting the consistency of systems of linear equations. This conceptual difficulty indicates that students tend to learn procedurally without in-depth conceptual understanding.

b. Difficulty Understanding Matrix Operations and Their Properties

In the topic of matrices and their operations, students did not experience significant difficulties in performing basic operations such as matrix addition and subtraction. However, difficulties arose in matrix multiplication operations where students made conceptual errors. Error analysis showed that students often applied the commutative property to matrix multiplication, namely assuming that AB = BA for any matrices A and B. This conceptual error reflects a negative transfer from the concept of real number multiplication to matrix multiplication.In addition, students also experienced difficulties in understanding the concepts of matrix transpose and inverse. Student M04 stated in an interview: "I can find the transpose by swapping rows for columns, but I don't understand why it has to be like that and what the point is." Similarly, student M09 revealed: "I know the formula for finding the inverse of a 2x2 matrix by heart, but for 3x3 or larger matrices I'm confused, especially when asked to explain the meaning of inverse."This conceptual difficulty aligns with research findings from Palcomtech Palembang, which showed that 20% of students made errors in matrix multiplication due to inaccurate understanding of the concept of multiplying row elements by column elements (Kusumawati et al., 2020). Furthermore, the study also found that only 5% of students made errors in addition and subtraction operations because they are relatively simpler and do not involve specific rules.

c. Difficulty Understanding the Concept of Elementary Row Operations (OBE)

Elementary Row Operations (EOP) is a fundamental concept in linear algebra used to simplify matrices and solve systems of linear equations. The results of this study indicate that students have difficulty applying EOP correctly. The main difficulties identified are: (1) the inability to determine an efficient EOP strategy to produce row echelon form, (2) errors in row manipulation, and (3) a lack of understanding of the meaning and purpose of each EOP step.Analysis of students' errors in problems requiring them to convert matrices to reduced row echelon form revealed a consistent pattern of errors. Many students made procedural

errors in OBE, with the following types of errors: errors in determining the pivot, errors in row multiplication by a scalar, and errors in row addition/subtraction. Student S11 stated: "I know there are three types of OBE, but I'm confused about when to use which one and what the order of the steps is."This finding is supported by research by Ayu et al. (2024) who analyzed student errors in systems of linear equations with elementary row operations. They found that students had difficulty manipulating OBE steps and often made incorrect conclusions. These difficulties indicate that students have not yet developed a strong conceptual understanding of the principles behind OBE and tend to apply them mechanically without in-depth understanding.

d. Difficulty Understanding Abstract Concepts: Vector Spaces and Linear Transformations

The concepts of vector spaces and linear transformations are the most abstract topics in the linear algebra curriculum and demonstrate the highest level of difficulty among students. Research shows that students also experience significant difficulties in understanding the concepts of vector spaces, subspaces, bases, and dimensions. Students tend to memorize formal definitions without being able to apply them in concrete contexts or understand their geometric meaning.In an interview, student M06 said: "The concept of vector space is too abstract, ma'am. I can read the definition many times but still don't understand what it means. The examples given are also hard to imagine." Student M15 added: "To prove something is a vector space, you have to check 10 axioms, but I don't understand why those axioms are important and what they mean."Similar difficulties were also encountered with the concept of linear transformations.

Students were unable to distinguish between ordinary functions and linear transformations and did not understand the fundamental properties of linear transformations, such as the preservation of addition and scalar multiplication. Student M08 stated: "Linear transformations are like functions, but they have certain requirements. I memorize the requirements, but I don't understand why they are necessary."This finding is in line with the statement that linear algebra has abstract concepts that make it difficult for students to understand the concepts and solve problems, so that learning media in the form of mathematical software that supports learning such as the Microsoft Mathematics application is needed to help visualize these abstract concepts (Salasiyah, 2017). The difficulty in understanding these abstract concepts is also confirmed by research by Sibgatullin et al. (2022) which states that algebraic thinking involving abstract concepts requires a special pedagogical approach to facilitate student understanding.

3. Factors Causing Conceptual Difficulties

Analysis of interview data, learning observations, and questionnaires given to students identified five main factors that cause conceptual difficulties in learning linear algebra.

a. Weak Prerequisite Ability

The results of the analysis show that students have a weak mastery of elementary algebra concepts, which are the foundation for understanding concepts in linear algebra. These weak prerequisite abilities include: (1) difficulties in integer and fraction operations, (2) inability to manipulate symbolic algebra, (3) weaknesses in understanding the concepts of functions and relations, and (4) lack of logical and analytical thinking skills.An M12 student admitted: "I've been weak in math since high school, especially algebra. So when I studied linear algebra, I couldn't even grasp the basic concepts." This finding is consistent with research by Hanifah and Nawafilah (2021), which stated that the factors causing students' learning difficulties in Linear Algebra are a lack of interest in learning, low basic skills, and a lack of ability to apply concepts to problem-solving.It can be concluded, therefore, that weak mastery of elementary algebra as a prerequisite skill causes students to have difficulty understanding linear algebra. This weakness encompasses number operations, symbolic manipulation, understanding functions, and logical abilities.

b. Less Effective Learning Methods

Observations of the learning process indicate that the learning method applied is still dominated by a conventional lecture approach with an emphasis on algorithmic procedures and formula memorization. In practice, lecturers tend to explain the steps to solve problems systematically without providing in-depth explanations of the underlying concepts. This condition causes students to tend to understand linear algebra mechanically and procedurally, rather than conceptually. Several students stated in the questionnaire that

linear algebra learning in class focuses more on "how" to solve problems than "why" a procedure is carried out, resulting in shallow understanding that is easily forgotten.Furthermore, the lack of use of visual approaches, such as diagrams, graphs, and geometric representations, makes abstract concepts in linear algebra, such as vector spaces, linear transformations, and the meaning of determinants, difficult for students to grasp. However, visualization and concrete applications are very helpful in connecting mathematical concepts to real-world contexts. Student M03 revealed that lecturers often explain formulas and calculation methods, but rarely provide visual representations or in-depth conceptual explanations. This statement indicates that students need a variety of learning methods that are more interactive and meaningful. Therefore, innovations in linear algebra learning are needed, such as the implementation of problem-based learning, the use of visual media and technology, and conceptual discussions that encourage critical thinking. These approaches are expected to improve students' conceptual understanding and reduce the learning difficulties that have arisen.

c. Lack of Meaningful Practice Questions

An analysis of the assigned assignments and practice problems shows that the majority of problems are procedural and repetitive, with relatively similar solution patterns from one problem to the next. This condition makes students accustomed to copying the steps of solving problems exemplified by lecturers without understanding the underlying mathematical concepts or principles. Students stated that they often work on problems similar to the examples on the board, so that success in solving problems depends more on memorizing procedures than understanding concepts.Furthermore, the lack of variety in questions that require higher-level reasoning, such as problem-solving, error analysis, or the application of concepts in new contexts, prevents students from being trained in critical and reflective thinking. Consequently, when faced with questions with slight modifications or different contexts, students tend to become confused and make errors. This suggests that the design of assignments and exercises needs to be directed at developing conceptual understanding so that students' mathematical thinking skills can develop optimally.

d. Limited Learning Resources and Learning Media

The questionnaire results showed that students experienced difficulty finding learning resources that met their needs. Available textbooks were often overly theoretical and lacked intuitive explanations or practical examples. Furthermore, limited access to learning technologies such as linear algebra visualization software (GeoGebra, MATLAB, Mathematica) made it difficult to visualize abstract concepts.Student M14 stated: "I tried to learn from textbooks, but the language was too formal and mathematical. I need simpler, more intuitive explanations." This finding highlights the need for the development of more accessible teaching materials and the use of technology to support the visualization of linear algebra concepts.It is understandable that students' understanding of textbooks is too theoretical and lacks applicable examples, as well as limited access to visualization technology, making the concept of linear algebra difficult to understand. Therefore, simpler, more intuitive teaching materials supported by learning technology are needed to improve students' conceptual understanding.

d. Motivation and Perception Factors towards Mathematics

The questionnaire results revealed that students have low motivation to learn linear algebra, influenced by negative perceptions of mathematics formed during their previous education. Students tend to view linear algebra as a difficult, abstract subject, and irrelevant to their future lives or professions. This perception leads to a lack of effort and active engagement in the learning process.An undergraduate student stated, "I'm studying linear algebra because it's a compulsory course, but I don't really understand its purpose and feel it's too difficult for me." This motivational factor aligns with the findings of Farida et al. (2021), who stated that students' difficulties in learning linear algebra are also influenced by a lack of interest in learning material perceived as abstract and difficult.Thus, students' low motivation to learn linear algebra is influenced by negative perceptions of mathematics formed during their previous education. The perception that linear algebra is difficult, abstract, and irrelevant reduces students' interest, effort, and engagement in learning.

B. Discussion

1. Implications of Conceptual Difficulties for Learning

The conceptual difficulties experienced by students in learning linear algebra at STAI Al Hikmah Tebing Tinggi have broad implications for the achievement of learning objectives and the development of students' mathematical competencies. Weak conceptual understanding not only impacts academic achievement in the linear algebra course itself but also hinders students' abilities in advanced courses that use linear algebra as a foundation, such as numerical methods, real analysis, and other advanced mathematics courses.Research by Untari et al. (2024) showed a very strong correlation (r = 0.812) between mastery of linear algebra material and student achievement in numerical methods courses. This finding indicates that conceptual difficulties in linear algebra will accumulate and impact subsequent courses. Therefore, addressing conceptual difficulties early on is crucial to ensure student success throughout the study program. Furthermore, the conceptual difficulties experienced by students indicate a gap between learning objectives that emphasize conceptual understanding and the reality of learning, which is still dominated by a procedural approach. According to constructivist learning theory, conceptual understanding is built through an active process in which students construct knowledge based on experience and interactions with the learning environment. When learning focuses solely on procedures and memorization without providing opportunities for students to explore, ask questions, and construct their own understanding, conceptual difficulties will persist.

2. Strategies for Overcoming Conceptual Difficulties

Based on research findings, several strategies can be implemented to overcome students' conceptual difficulties in learning linear algebra, as follows:

a. Strengthening Prerequisite Skills. Given that weak prerequisite skills are a major contributing factor to conceptual difficulties, remedial or bridging courses should be designed to strengthen students' understanding of elementary algebraic concepts before beginning linear algebra instruction. These courses could include a review of number operations, algebraic manipulations, systems of equations, and function concepts with a more in-depth and interactive approach.

b. Implementing a Conceptual Understanding-Oriented Learning Approach. Learning linear algebra needs to integrate various representations (symbolic, numeric, geometric, and verbal) to help students build a solid conceptual understanding. Visual and geometric approaches are crucial, especially for abstract concepts such as vector spaces, linear transformations, and eigenvalues. The use of visualization software such as GeoGebra, MATLAB, or Desmos can help students see geometric representations of linear algebra concepts and facilitate intuitive understanding.In her research on the development of linear algebra modules, Salasiyah (2017) suggested the use of interactive learning media and approaches that allow students to learn independently with guidance. The results of this study showed that modules developed using a constructivist approach effectively improved students' understanding of linear algebra concepts.

c. Developing Contextual and Applicable Teaching Materials. Linear algebra teaching materials need to be developed with a more contextual approach, connecting abstract concepts with real-world applications in various fields such as computer graphics, data analysis, recommendation systems, and cryptography. By recognizing the relevance and practical applications of linear algebra, student motivation and engagement in learning are expected to increase.

d. Implementation of Active and Collaborative Learning. Active learning models such as problem-based learning, inquiry-based learning, or flipped classrooms can encourage students to actively engage in the learning process, explore concepts, and construct their own understanding. Collaborative learning through group discussions, peer tutoring, or cooperative learning can facilitate the exchange of ideas and understanding among students, which has been proven effective in improving conceptual understanding.

e. Providing Assessments That Measure Conceptual Understanding. Learning assessments should be designed to measure not only students' procedural skills but also their conceptual understanding. Assessment questions should include questions that encourage students to explain, analyze, connect, and apply concepts, not just calculate or follow procedures. Regular formative assessments can provide constructive feedback for students to identify and address their conceptual difficulties.

3. Contribution to the Development of Linear Algebra Learning

The results of this study provide an important contribution to the development of linear algebra learning at STAI Al Hikmah Tebing Tinggi in particular and higher education in general. Identification of the types of conceptual difficulties and their causal factors can serve as a basis for designing more effective and targeted learning interventions. The finding that the greatest difficulties lie with abstract concepts such as vector spaces and linear transformations indicates the need for more time allocation, more innovative pedagogical approaches, and the use of technology to facilitate understanding of these concepts.Furthermore, this study emphasizes the importance of adopting a balanced learning approach between procedural and conceptual aspects in teaching linear algebra. As revealed in research on students' difficulties in learning linear algebra, it is necessary to develop learning strategies that focus not only on computational skills but also on a deep understanding of fundamental concepts (Farida et al., 2021). This way, students will not only be able to solve linear algebra problems mechanically but also understand the meaning, rationale, and application of each concept learned.

4. Research Limitations and Recommendations for Further Research

This study has several limitations that should be considered when interpreting the results. First, the study was conducted at a single institution, so generalizing the results to a broader context requires caution. Replication studies with larger samples and involving multiple institutions are needed to validate the findings.Second, this study focused on identifying conceptual difficulties and their contributing factors, but did not develop and test the effectiveness of specific interventions to address these difficulties. Further research could develop and implement learning interventions based on the findings of this study, then evaluate their effectiveness through experimental designs.Third, this study used a combination of quantitative and qualitative methods, but a more in-depth analysis of students' cognitive processes in understanding linear algebra concepts through think-aloud or eye-tracking protocols could provide richer insights into the mechanisms of conceptual difficulty. Neurocognitive research on linear algebra learning could also be an interesting area for future exploration.

IV. CONCLUSION

Based on the research results and discussion, it can be concluded that students of STAI Al Hikmah Tebing Tinggi still experience significant conceptual difficulties in learning Linear Algebra. These difficulties include understanding systems of linear equations, matrix operations, elementary row operations, and abstract concepts such as vector spaces and linear transformations. The high percentage of students with low levels of understanding indicates that learning Linear Algebra is still dominated by a procedural approach without being balanced by adequate conceptual understanding. The main factors causing difficulties include weak mathematical prerequisite skills, less varied learning methods, limited learning resources and media, lack of meaningful practice, and low student learning motivation. These findings emphasize the importance of improving learning strategies to continuously improve students' conceptual understanding.

V. SUGGESTION

Based on these conclusions, it is recommended that lecturers strengthen students' prerequisite skills through remedial programs and implement conceptual understanding-oriented learning with visual, contextual, and technology-based approaches. Institutions need to support the development of interactive teaching materials and the provision of relevant learning media. Further research is recommended to develop and test the effectiveness of innovative learning models or media to address students' conceptual difficulties in Linear Algebra.

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